Convective Motion as Indicated by Visual Tracers

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ABSTRACT

Time-lapse photographs taken of a visual tracer laid in horizontal lines at several levels, one above the other, show convective motion of the air in a vertical plane. Through minor improvements in technique a three-dimensional picture of the air motion could be achieved.

1. What was done

On 24 July 1967 a crew of four and two small aircraft went to Shawave Dry Lake, ~65 mi northwest of Reno. We laid a course 4 mi long parallel to the wind in the middle of the lake. The closest mountains were 7 mi distant.

Five miles from the course and perpendicular to it we stationed our observation post and operated a time-lapse 16-mm camera. One aircraft was equipped with a device for ejecting a oil fog trail (described by Nielsen and Berry, 1969); it began a flight 500 ft above the course and let out "smoke" in the sequence of 1 sec on, 4 sec off. After one pass the aircraft climbed 500 ft and followed the course again, but in the opposite direction. This operation was repeated until the last pass was 2500 ft above the lake.

2. What we saw

We saw the "smoke" puffs diffuse, some in 20 sec, others in 5 min, and move against the background. From the aircraft we noticed only a very slight drift of the smoke off the course. We tried to trace the motion of the "smoke" with a camera lucida in order to see immediately if there were any pattern to the smoke's motion. But this proved impossible; there were too many smoke puffs and they moved too fast.

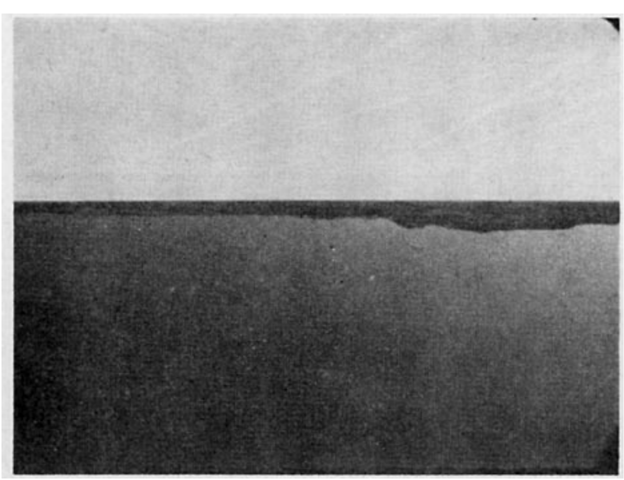

FIG. 1. One frame from the time lapse movie sequence. The aircraft is moving to the right.

However, when the time-lapse movie (with the triggering done manually) was developed and projected in a stop-motion projector, the motion of the air became more readily discernable. We could then see that some puffs moved up and others down, and still others (which were caught between them in the shear) were rapidly torn apart and diffused. A single frame from the movie is shown in Fig. 1.

We traced the motion of the smoke, frame by frame, and superimposed two sets of passes, one of five passes from 1200–1220 local time and the second of four passes from 1336–1352. Although there was a time delay as the aircraft worked its way upward, there emerged the interesting patterns shown in Figs. 2 and 3.

Each arrow shows the path of the smoke from inception until it could no longer be seen. While the timing is not shown, it was obtained from the film. The updrafts in the right-hand thermal in Fig. 3 are approximately 10 m sec^{-1}. The smoke puffs were approximately 50 m long and 250 m apart, from center to center. The author's concept of the thermal boundaries has been sketched in.

The dispersion of the smoke puff is due almost entirely to the turbulence existing in the atmosphere and only negligibly to the turbulence produced by the aircraft. The smoke coming from the exhaust manifolds of the aircraft enters the downwash, then spreads sideways and strongly curls up and over into the center. After 30 sec, if the atmosphere is still, all motion in the smoke plume has essentially stopped. The plume has a diameter corresponding to the wing span of the aircraft, but greater vertically than horizontally.

The entire plume will drift down a bit due to the downwash of the aircraft, but it does not further diffuse

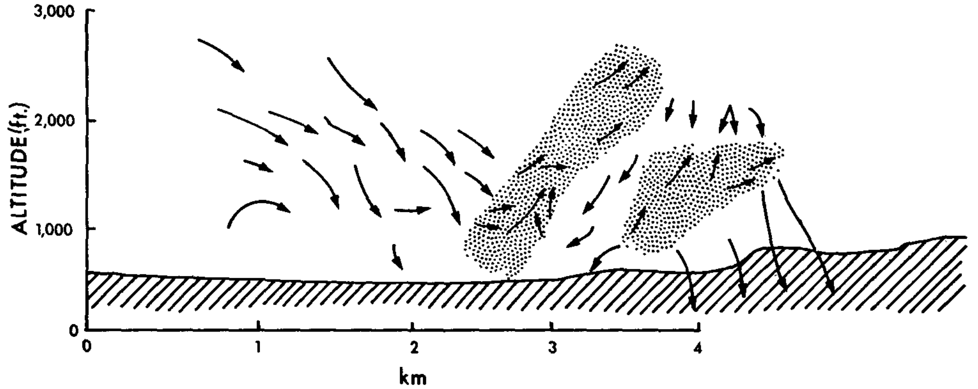

FIG. 2. Paths of smoke from five aircraft passes between 1200–1220 on 24 July 1967.

of its own accord. A smoke plume placed in the smooth air of a lee wave was observed to remain intact for 30 min when it drifted out of sight (see Nielsen and Berry, 1969).

3. Observations

The two thermals in Fig. 2 are early thermals in which updrafts and size are moderate; the data are not sufficient to determine whether or not they eventually merge. The two thermals in Fig. 3 are large and strong with a spacing of ~2 km and diameters of ~1 km. The upwind thermal slants and perhaps shields the other thermal which rises almost vertically. The vertical thermal is the strongest.

Smoke paths travel upward a distance corresponding to the diameter of the thermal with no mixing motion. This is true at the edge of the thermal as well as in the middle. The vertical velocity at the center seems to be no greater than that near the edges. There is no clear evidence of a buoyant, circular vortex nor of large-scale internal mixing.

Pilots in this area regularly observe that two sailplanes can start in separate thermals at different ends of a dry lake and, without ever leaving their own thermal, will approach each other at a height of ~4000 ft above the ground. Until that point the thermals do not get noticeably larger with height. Here we see pictures of thermals that may be coming together; unfortunately, the smoke trails were not continued to a great enough height to see if this was the case.

The shear is seen to be greater on the upwind side of the right-hand thermal of Fig. 3. This is also a common observation of sailplane pilots. The turbulence, as judged by the rate of smoke diffusion, was about the same inside as outside the thermals; however, the upward velocity in the thermal was greater than the downward velocity outside. From either the ground or aircraft, there was no discernable rotary motion to the thermals.

4. In retrospect

The original objective of this experiment was to see if thermals grow larger with altitude by expansion or collection. Initial experiments on two preceding days had the smoke aircraft attempt to spot a thermal with smoke and re-spot it as it rises. This was found to be possible by flying a figure 8 pattern, but it did not fulfil the experimental objectives of finding the organization of thermals over a dry lake bed. The regular flight

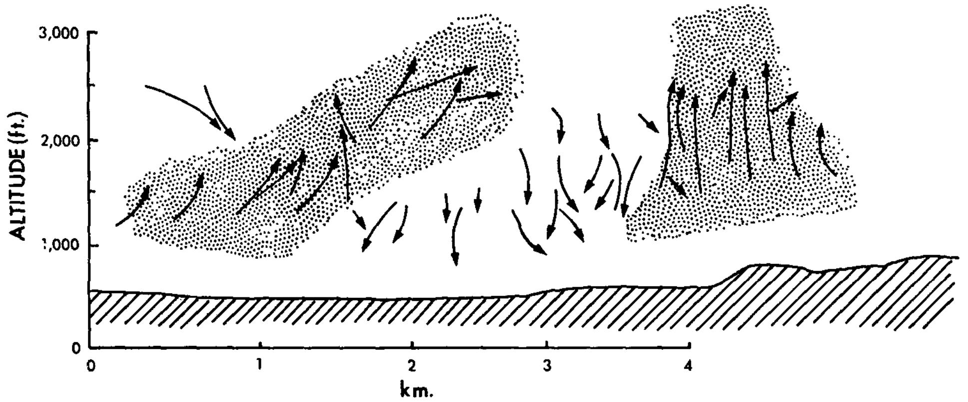

FIG. 3. Paths of smoke from four aircraft passes between 1336–1352 on 24 July 1967.

pattern that finally evolved proved to be successful and efficient, but even this can be improved upon.

A better way would be to place smoke in several levels at once, either with several aircraft or by dropping a specially designed pyrotechnic device. It does not really matter that the smoke is put at preset altitudes. It is only necessary that enough smoke puffs are available to sufficiently represent the convective motion being studied. The camera makes data reduction very easy and straightforward.

A second improvement would be to fly a race-track pattern to capture a depth to the thermals by putting smoke in two vertical planes. Two cameras should be used, one (as here) perpendicular to the prevailing wind, and the second parallel, looking along the aircraft track. This particular camera orientation is chosen not because it records any more information but because it makes the data reduction infinitely easier, which is one really good feature of this experiment.

5. In prospect

What is demonstrated here is one way to see convective patterns in clear air. It is important that we see these patterns to check them against the ideas we have developed from laboratory and theoretical studies.

The simplicity of this experiment makes it easily reproducible, as it should be. The technique can be used to investigate convective patterns in different seasons, times and places.

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REFERENCE

Nielsen, K. W., and E. X Berry, 1969: Development and use of an airborne marker system for atmospheric research. *J. Appl. Meteor.*, 8, 502–505.